New Technologies for Optical Radiation Measurements
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INTRODUCTION

CIE Division 2 covers the area of physical measurement of light and radiation, inc photometry, colorimetry, and radiometry, for light sources, materials, and detec Although theories and principles in this field are well established in its long h methodology is changing and uncertainty is steadily improving with the introduction of new technologies.

This workshop is not a series of presentations, but is planned as a series of active discussions by panelists and the audience on several hot issues which are now gaining attention. The four topics below were chosen to stimulate discussion for the three hour duration of the workshop. Each topic introduces different methods to achieve the same purposes. Each topic involves new technologies which may lead to a dramatic improvement of accuracies and/or facility conveniences. However, there are some misunderstandings or lack of knowledge among the users about new methods or new instruments, which are causing unexpected errors.

In this workshop, the ideas and the experiences of the experts on these subjects will be exchanged, and the knowledge of the new technologies will be updated, thus providing useful information or guidance to the measurement community. The discussion should also be of great help for shaping the future work of CIE Division 2.

Discussion

1. Transfer standards for photometry – pros and cons of lamps and detectors.

In photometry, standard lamps have been most often used to transfer and maintain luminous intensity and luminous flux standards. For luminous flux, the transfer must be done by standard lamps. For luminous intensity or illuminance, however, $V(\lambda)$-corrected detectors (hereafter called photometers) are becoming more and more popular as transfer standards. The worldwide shortage of standard-quality lamps also necessitates alternative means.

The advantages of photometers are that they are, in general, robust and less subject to mechanical shocks, not subject to aging by use, less critical in orientation alignment, and have a large dynamic range. Their short-term reproducibility is generally excellent. However, there seems to be a large variation in the quality of commercial photometers. Some photometers exhibit aging while in storage, and the long-term stability of photometers are often overestimated. People also tend to forget that the color temperature of the source must be known when the photometers are used to measure illuminance, and distance must be measured accurately to determine luminous intensity.

Standard lamps are subject to aging by use (burning time), to mechanical shocks due to fragile filaments, and to drift of the light output during operation. However, some good lamps are reportedly reproducible for more than 20 years with limited burning time and careful laboratory practice. The lamps do provide luminous intensity scales as well as color temperature scales, but need distance measurement to provide known illuminance, which is subject to inverse-square law errors.

One should be aware of the advantages and the disadvantages of photometers and lamps, and they should be selected based on the intended application. Recent experiences and data on the problems in using photometers and lamps will be discussed, and useful information as to how to use standard photometers and lamps will be developed during the discussion.

The discussion on this topic will also be a good input for TC2-04 (Secondary standard sources), and TC2-37 (Photometry using detectors as transfer standards) which has just started.

2. Luminous flux measurement –

(1) How to best utilize integrating spheres and goniophotometers

The total luminous flux of sources are generally measured by using either integrating spheres or goniophotometers. The general rule is that one can use integrating spheres to measure sources only against standard sources of the *same or similar* type (substitution photometry). Goniophotometers can be used to measure sources having any luminous intensity distributions, but are more difficult to use and expensive, and measurements are slower resulting in longer burning time of lamps.

Even though integrating spheres are intended to be used for strict substitution measurements, there are many cases where it is necessary to measure test lamps against standard lamps of different types because of the limited types of standard lamps available from national laboratories. Then how big are the errors? How similar should the test lamps and standard lamps be? These and other questions will hopefully be answered in the discussion here. Recently, a method has been developed to make corrections for the spatial non-uniformity of the sphere response. Can this method be a remedy for substitution measurements in integrating spheres? What are other recent improvements in integrating spheres? There have also been constant efforts to improve goniophotometers. What are the recent improvements? How can one choose between integrating spheres and goniophotometers for certain applications?

CIE Publication No.84 (Measurements of Luminous Flux) does not answer these questions clearly. The discussion on this topic might lead to new work for Division 2.

(2) Measurement of incandescent light sources – problems of repeatable and reproducible results with limited resources.

There is a particular problem in India in the measurement of total luminous flux of incandescent lamps, both for GLS (General Lighting Service) and automotive applications. Since most production in India is made in small companies, expensive test and measuring equipment are not affordable.

Sphere photometry is employed for the measurement of total luminous flux. Short comings of the test equipment construction, sphere paint, photometer accuracy, unavailability of standard lamps result in large errors and the measurements are not reproducible. Unless the optical metrology is improved, improvements to the quality of these lighting products cannot be effectively developed. There is thus an urgent need to develop inexpensive but reliable test methods for the measurement of luminous flux of incandescent light sources.

The discussion here will hopefully lead to the solution of such problems in developing countries.

3. Diode-array spectroradiometry and tristimulus colorimetry

The most accurate way to measure the spectral power distributions and the color of light sources would be to use double monochromators of a mechanical scanning type, but they are expensive and measurements are time consuming. Tristimulus colorimeters provide for much faster and inexpensive color measurements. More recently, photodiode-array type spectro-radiometers, which are also fast but not always inexpensive, are becoming more popular for applications in colorimetry and spectroradiometry.

However, there are several problems which many users of instruments are not aware of, and the uncertainties are often underestimated. Most of these instruments employ a single grating installed in a compact unit, and are subject to stray light. Many instruments are not provided with a means for calibration by users, and therefore are used for a long period of time relying on the manufacturer's initial calibration. Some instruments suffer from a serious long-term drift. Most instruments have fixed bandwidth, which can be a problem for discharge lamps with strong emission lines. These instruments often have changeable input optics, which can cause problems through misuse. There are also large variations in the characteristics of diode-array instruments. It is difficult to quantify the errors users are encountering in each application.

Tristimulus colorimeters are still an option for inexpensive color measurements. As long as the source under test is *similar* to a standard source against which the instrument is calibrated, they show excellent accuracy. But, how similar the sources should be is the question. Are there any guidelines for this? Some expensive colorimeters having highly accurate spectral matches to the standard CIE definitions can have accuracy greater than that of most diode-array systems.

The discussion on this topic will provide input for TC2-16 (Characterization of the performance of tristimulus colorimeters) and TC2-30 (Diode-array radiometry).

4. Improving the accuracy of photometric base scales – how can we bring the accuracy of cryogenic radiometers into photometric standards?

The accuracy of photometric standards depends on the uncertainty of the primary scales at national laboratories, which is now in the order of 0.5 %†. The primary scales are now realized based on absolute detectors including cryogenic radiometers. The cryogenic radiometers are basically electrical substitution radiometers working at a near absolute-zero temperature. The cryogenic radiometers are becoming more and more affordable and common in national laboratories. They now provide uncertainty in the order of 0.01 %. If this is the case, why is there still a gap of the uncertainty between photometric scales and radiometric scales? The obstacles may be instability of transfer standards, behavior of filters, instability of sources, and differences in geometry, etc. How can we overcome these problems and achieve uncertainty of 0.1 % or better in photometric scales?

After discussion on these subjects, there will be an open discussion period for any issues of interest to the attendees. Suggestions are welcome on the current or future work for CIE Division 2.

† Throughout this paper, uncertainty is given as relative expanded uncertainty with coverage factor $k=2$, thus a two standard deviation estimate.